Summary of work from Grant FA9550-04-1-0136, "Femtosecond Laser Assisted Health Monitoring of Critical Structural Components".

During this period, work was performed in several areas as listed below.

1) Study of collateral damage to turbine blade materials during high intensity ultrafast laser interaction (Yalisove, Pollock, Jones)

Jet polished transmission electron microscope (TEM) samples of single crystal turbine material were machined using ultrafast lasers. The TEM images, before and after machining, revealed the collateral damage to the material that was left. Dislocation analysis was performed as a function of pulse intensity. The results are quite unlike collateral damage from nanosecond laser machining, electron discharge cutting, or mechanical drilling. The latter methods produce micro-cracks, stacking faults, and other potentially dangerous defects that could lead to fatigue initiation. Only a dislocation network in the softer component was observed that would most likely not cause fatigue initiation cracks. These results are similar to gas gun experiments performed at Los Alamos National Laboratory where high strain rate deformation leads to similar defect microstructures. These results suggest that we can indeed use ultrafast lasers as a probe of the health of structural turbine blades without damaging the blades we wish to study.

2) Feasibility study of laser induced breakdown spectroscopy (LIBS) in assessment of turbine blade health (Yalisove, Pollock)

Studying the chemistry of the exposed regions of a turbine blade may reveal useful information about the health of the blade. Ultrafast LIBS may offer the opportunity to measure the chemistry with increased signal to noise (over nanosecond systems) while removing a very minimal amount of material from the blade, leaving the remaining material undamaged. We have set up an ultrafast LIBS system to assess whether or not we can reduce the fluence necessary for chemical analysis. We have shown that the damage threshold is far below the LIBS threshold and we have proposed a mechanism for ultrafast laser material interaction which not only explains this phenomena, but suggests a novel method to greatly reduce the LIBS threshold such that only ~10nm of material needs to be removed for LIBS analysis. Recent results from other experimental and theoretical groups have suggested that at a fluence just above the ablation threshold a liquid layer is ejected. Hence, there would be no ionized plasma to fluoresce. We are currently in the process of bringing in a second, 10 nanosecond delayed pulse, parallel to the surface of the blade being interrogated, to vaporize this liquid layer after it travels about 10 – 100 microns from the blade. We expect to see a strong signal from this delayed interaction.

We have also begun to collect data for standard analysis of particular impurities (like SiO_2 from sand ingestion during gas turbine service) in the turbine blade system.

3) Feasibility study of terahertz spectroscopy for determination of thermal barrier coating thickness (Whitaker)

Terahertz spectroscopy using ultrafast laser derived sources has been successful at studying properties of dielectrics for some time. We have set up a reflection system to assess the thickness of the thermal barrier coatings (TBCs) on gas turbine blades. We have been successful in demonstrating that features in the terahertz spectrum correspond to reflections from the front surface and back surface of the TBC. The separation in time that is detected is a direct measurement of TBC thickness. This is very encouraging because we should, in principle, be able to extend this technique to resolutions on the micron scale (in thickness) and may be able to discern the onset of oxidation of the underlying bond coat when it grows to a thickness on the order of 1-20 microns. This oxide growth has been identified as a key parameter for turbine blade prognosis.

4) Feasibility study of turbine blade radiography using ultrafast laser generated x-rays (Nees, Mourou)

X-rays have been generated in a ~micron sized volume using a lambda-cubed high intensity ultrafast laser with adaptive optics. These x-rays are very bright and have characteristic x-ray peaks on a Bremstraahlung background. The x-rays are bright enough that they can penetrate a Ni based superalloy turbine blade and form a radiographic image on film. Furthermore, because the source spot size is so small, 100 times magnification is possible. We have demonstrated that we can form a radiograph of the edge of a real turbine blade in a reasonable length of time (1 minute).

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INTERACTION (YALISOVE, POLLOCK, JONES).
2. FEASIBILITY STUDY OF LASER INDUCED BREADKDOWN SPECTROSCOPY (LIBS) IN ASSESSMENT OF TURBINE BLADE HEALTH (YALISOVE, POLLOCK).
3. FEASIBILITY STUDY OF TERAHERTZ SPECTROSCOPY OF DETERMINATION OF THERMAL BARRIER COATING THICKNESS (WHITAKER).
4. FEASIBILITY STUDY OF TURBINE BLADE RADIOGRAPHY USING ULTRAFAST LSER GENERATED X-RAYS (NEES, MOUROU).

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